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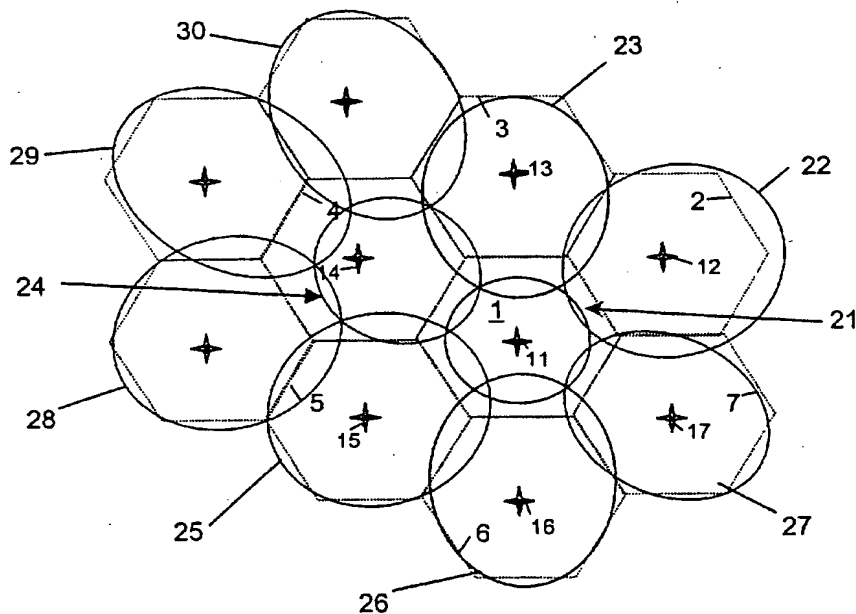
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(54) Title: INTELLIGENT CONTROL OF RADIO RESOURCES IN A WIRELESS NETWORK

(57) **Abstract:** A method of controlling radio resources in a cellular wireless network comprising a plurality of fixed antennas providing overlapping radio coverage, the method comprising dynamically adjusting the radiation patterns of the antennas using co-ordinated distributed control to optimise capacity. The wireless network may be a cellular mobile network or part thereof comprising a plurality of cells, each cell having a base station comprising an antenna, and the method may then further comprise determining the concentration of mobile stations in each cell and changing the radiation/reception pattern of the antennas of some or all of the base stations in response to the concentration of mobile stations in each cell.

INTELLIGENT CONTROL OF RADIO RESOURCES IN A WIRELESS NETWORK

The invention relates to the intelligent control of radio resources in a wireless network,
5 and in particular but not exclusively to the control of resources in a cellular mobile
telephone network.

In mobile cellular telephone networks subscribers are dynamically allocated channels
from a pool of available channels. Techniques for increasing the efficiency of channel
10 usage in mobile networks are essential in order to handle the complexity of third
generation mobile communications. Previous work on analogue and second generation
mobile communications has led to several algorithms being proposed to optimise
channel usage and minimise call blocking probability. Some channel assignment
schemes presented in the literature have improved the performance of the basic fixed
15 channel assignment strategy for different traffic densities (macro/micro/pico cellular
networks) over different traffic load conditions. However, most of the solutions
proposed have an entirely reactive approach: the response to a series of events follows
an algorithm that is prepared to react to specific situations. This limits their efficiency.
Even those schemes that contain adaptive features are not ideal. Some schemes are
20 completely centralised (which is impractical for real implementation because of
computational complexity making them too slow, or because the network would
become overloaded with signalling messages) or are distributed, but restricted to
individual base stations which again limits their efficiency.

25 The mechanism known as Fixed Channel Assignment (FCA) is too limiting for mobile
networks and several strategies have been proposed to maximise frequency channel
allocation and minimise call blocking probability. A detailed survey describing
dynamic channel allocation (DCA) schemes and FCA-based schemes, including those
with channel borrowing, is given in M. Zhang and T.-S. P. Yum, "Comparisons of
30 Channel Assignment Strategies in Cellular Mobile Telephone Systems", IEEE Trans. on
Vehicular Technology, vol. 38, no. 4, November 1989, and H. Jiang and S. S.
Rappaport, "CBWL: A new channel assignment and sharing method for cellular
communication systems", IEEE Trans. on Vehicular Technology, vol. 43, no. 2, May

According to a first aspect of the present invention, there is provided a method of controlling radio resources in a cellular wireless network comprising a plurality of fixed antennas providing overlapping radio coverage, the method comprising dynamically adjusting the radiation patterns of the antennas using distributed co-operative control.

5

Typically, the dynamic adjustment of the radiation patterns is carried out in order to satisfy varying demand patterns from wireless terminals. The adjustment can therefore maintain overall coverage and equalise the load across the cells.

10   The use of distributed co-operative control allows the radiation patterns of antennas to be adjusted quickly and efficiently in response to variations in demand across the network without the intervention of a central control system. The radiation patterns are preferably adjusted in response to negotiations between base stations.

15   The invention can be applied to any wireless network, but in preferred embodiments the wireless network is a cellular mobile network or part thereof comprising a plurality of cells, each cell having a base station comprising one or more antennas, and the method comprises determining the concentration of mobile stations in each cell and changing the radiation/reception pattern of the antennas of some or all of the base stations in a co-
20   ordinated way in response to the concentration of mobile stations in each cell. The wireless network may also, for example, be a fixed wireless access network.

Preferably agent technology is used to co-ordinate this distributed control of the radiation pattern of the antennas, and in preferred embodiments the agent technology is
25   used to control the antennas to dynamically optimise the radio coverage of the network to maximise the capacity of the network. The agent technology may also be used to control frequency channel assignment and handovers between cells.

The agent technology preferably uses agents comprising a control unit, the control unit
30   comprising a reactive layer for managing radio coverage within a cell and one or more planning layers for optimising radio coverage within one or more cells in response to local changes.

5

The invention may also be used in fixed wireless access (wireless in the local loop) to manage capacity on demand. This is similar in concept to cellular mobile systems, but the wireless terminals do not move.

5   In order to accommodate multiple networks and services with multiple bit rates within a limited frequency band, resource flexibility is one of the most important requirements in third-generation networks. A distributed control system, and in particular a multi-agent system, is able to provide this flexibility and is also able to increase the robustness of the network by allowing negotiation when conflicts occur. Such negotiation produces

10   antenna pattern control that can enable a failure of a single cell to be covered by adjacent cells, who themselves have some of their capacity off loaded to cells in a second ring surrounding the failed cell by agent control of their antenna patterns. Such negotiation will also allow a new cell to advertise its existence and be seamlessly added to the network without manual network reconfiguration. This concept can be used to

15   provide temporary increase in network capacity via a portable base station to cover large predictable increases in network demand, such as would be required at a large sporting event.

A Multi-Agent System (MAS) can be defined as a group of agents with specific roles in

20   an organisational structure. The agents interact with the environment and with each other in a co-ordinated way, as collaborators or competitors, seeking to fulfil the local or global aims of the organisation. The definition of an agent and the main characteristics that distinguish agents from other software systems can de found in J. P. Müller, "The Design of Intelligent Agents: A layered Approach", Lecture Notes in Artificial

25   Intelligence 1177, Sub-series of Lecture Notes in Computer Science, Edited by J. Carbonnel and J. Siekmann, Springer, 1996. Agent architectures are classified by the degree of reasoning incorporated by the agent, from a completely logical model (known as Beliefs, Desires, Intentions (BDI) architectures) to a fully reactive model with no symbolic representation.

30

Recent research has shown that reactive approaches, while necessary, are not sufficient for efficient control of resources: the base stations should have an adaptive behaviour, not only to improve their own channel usage, but also to co-operate with other base

Figure 1 shows schematically the hexagonal cell pattern of a typical idealised mobile telephone network. In this figure, seven cells 1-7 are shown. Each cell has a base station 11-17 at its centre. The radio coverage footprint provided by each base station is not exactly hexagonal and is illustrated by the overlapping circles 21-27, although the coverage is not necessarily circular. This is the coverage that has been assumed for previous work on frequency channel assignment and agent technology controlling handover.

If there are a lot of mobile telephone users in cell 1, so that the capacity of cell 1 needs to be increased, the smart antenna 12 in cell 2 is controlled by the agents (see below) to change its coverage pattern 22 to provide more coverage in cell 1, as shown in Figure 2. This is repeated in smart antennas 13 to 17 whose coverages are commanded to those shown in 23 to 27 thus shrinking the coverage of cell 1 to that of coverage pattern 21 of Figure 2. It is important to ensure that some coverage is maintained across the whole region covered by the network, so other cells may also need to be modified to prevent "holes". For example, the coverage of cell 14 in Figure 2 is now incomplete due to its own high traffic load and so revised cell coverage patterns 28 to 30 provide this coverage from cells adjacent to it. For simplicity, this further modification is not fully shown in Figure 2.

Application of this invention to the GSM system can be done in a low dynamic way where the change in cell coverage can last for minutes and applies to all frequencies and time slots used within a cell or sector. Alternatively it can be applied in a fast dynamic way where calls emanating from several high traffic sources are marshalled (by in cell hand-overs) into one or more GSM time slots and the cell antenna pattern coverage switches between time slots. The GSM standard allows for up to eight full-rate mobile units to share the same frequency. Digitally encoded samples are transmitted during each time slot of 577 µs duration. A frame of eight time slots repeats every 4.6 ms. Thus the GSM smart antenna system would be able to switch to up to 8 different antenna pattern coverages on the uplink and downlink, maintaining a given pattern for the duration of a time slot.

execution tasks that actually change radio coverage and terminate appropriately unsuccessful requests.

The agent has a knowledge base 35, which contains the world model 36 containing the environment information and everything necessary for the operation of the reactive layer 40. The mental model 37 contains the complete information about the agent, about the radio footprints and possibly history of traffic load in the cell. Finally the social model 38 has relevant information about other agents' data.

The agent further comprises a control unit 39, structured to include a reactive control layer 40 that is responsible for fast accommodation of traffic demand, a local planning control layer 41 using other strategies to optimise the local radio patterns and the co-operative control layer 42, responsible for coverage balancing across a larger area. The agents follow a collaborative strategy using a protocol such as the Contract-Net Protocol. A brief description of each layer implementation is given below.

The reactive layer 40 uses a reactive algorithm to manage the radio coverage within the cell, whether this is static or uses beam switching. It is particularly important to deal with handover requests or with new connections.

The local planning layer 41 considers local changes to optimise coverage within a cell or a cluster of cells. This ensures optimum coverage of radio signal for existing mobiles, subject to the constraint that coverage throughout the cell must be maintained to allow for new connections.

Finally the co-operative layer 42 starts a joint plan when the traffic load of the compact coverage pattern does not allow efficient performance of the local planning scheme. The agent in the hot cell or areas of hot cells, using the contract-net protocol, requests its neighbouring cells or areas to make offers for moving their radio footprint into part of the hot cell region. To be able to make a bid, the adjacent cells need to compute a utility function that requires the load conditions of its compact pattern. Therefore, they request offers of capacity (constrained by terminal distribution) to their adjacent cells. These cells use another utility function to prepare their bids before sending offers. The cells

- The local planning layer 41 manages the antenna patterns to maximise the effective use of the network within the control of a particular RRA where they have no impact on other RRAs. One solution aims to minimise the total interferance noise resulting from a cluster of mobiles by directing antenna gain in the direction of those clusters with high mobile transmit powers and high cluster populations. This area over which such minimisation occurs can in principle range from one cell to a number of cells managed by the same RRA.

- The reactive layer 40 has to make fast decisions on base-station assignment and connection admission control (CAC) in response to connection requests. It does this following the policy imposed by the planning layers.

Considering the reactive and planning function in more detail: -

Reactive Layer: The reactive layer 40 works at an individual connection request level and performs many of the same functions that would be undertaken in a conventional RNC (assigning the connection to a base station (Node B), and performing Connection Admission Control (CAC)), but rather than use fixed algorithms it does this using context dependent policies created by the planning layer, as shown in Figure 4.

A connection request 43 is first considered for assignment 44 to a Node B 45 using an algorithm or set of rules passed down (dynamically) from the planning layer. These rules take into account the particular antenna patterns in use at that time. The assigned Node B is the one that is allowed to perform power control, and which subsequently accepts or rejects the call. Standard assignment mechanisms can be passed down as a policy, or proprietary schemes or even new schemes. Since these can be changed dynamically, the planning layer can respond to local resource issues by changing the assignment strategy in line with changing antenna radiation patterns.

This is followed by CAC 45 which operates in a similar way. Should the assignment 44 or CAC 45 fail, an exception management module 46 will check if any local rules can be applied to see if further modified attempts should be made, or whether the failure

and hybrid approaches linking the former with hill climbing methods) are candidates for faster run time implementations.

It will be appreciated that the arrangement above is not intended to restrict the scope of

5   the invention. For example, the embodiment described is concerned with the use of mobile telephones, but the invention can be applied to, for example, fixed wireless networks. Although the implementation has been described with reference to agent technology, any form of dynamic distributed co-operative control of the smart antenna can be used to optimise the coverage of a network.

8.   A method as claimed in claim 7, wherein the local planning layer uses genetic algorithms to construct coherent plans for optimising the radio coverage.

9.   A method as claimed in claim 7 or 8, wherein the control unit further comprises a co-operative layer for negotiation with other agents over a wider region

10.   A method as claimed in any preceding claim, wherein the determination of radiation patterns includes an input based on the predicted demand within a group of cells.

11.   A method as claimed in any preceding claim, wherein the wireless network is a wireless local loop network.

12.   A method of controlling radio resources in a cellular wireless network comprising a plurality of fixed antennas providing overlapping radio coverage, the method comprising using artificial intelligence techniques to control the radiation patterns of the antennas.

13.   A method of controlling a cellular wireless network comprising base stations, each base station comprising an antenna having a dynamically variable radiation pattern, the method comprising co-ordinating the radiation patterns of the antennas using distributed co-operative control.

14.   A method of optimising the allocation of radio resources in a mobile telephone network, comprising tracking changes in demand by mobile subscribers and co-ordinating the radiation patterns of smart antennas at base stations in the network using distributed co-operative control.

15.   A method of co-ordinating the radiation patterns of smart antennas within a wireless network, comprising using hybrid agent architecture to support negotiation between base stations within the network.
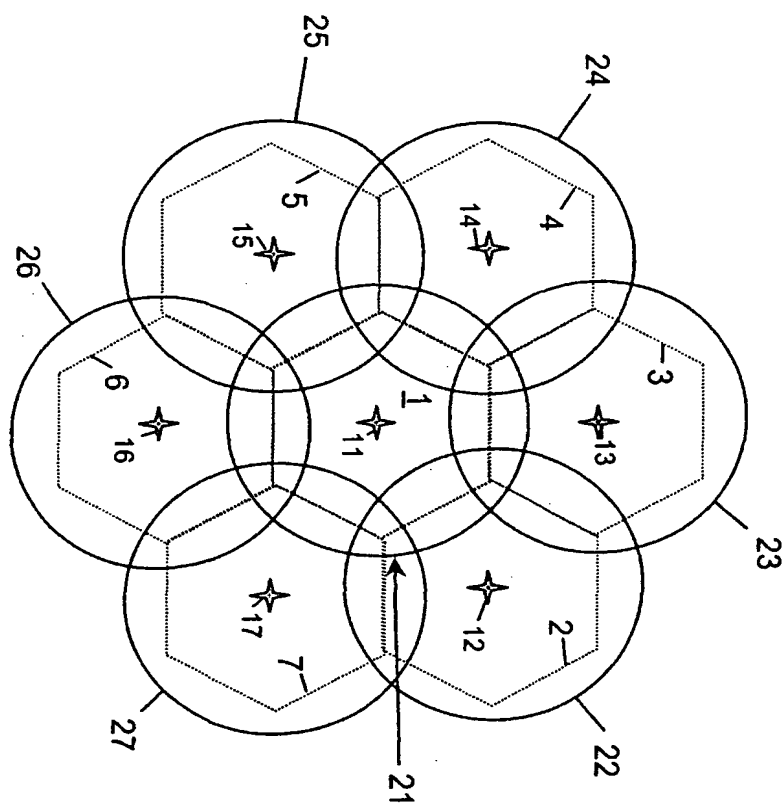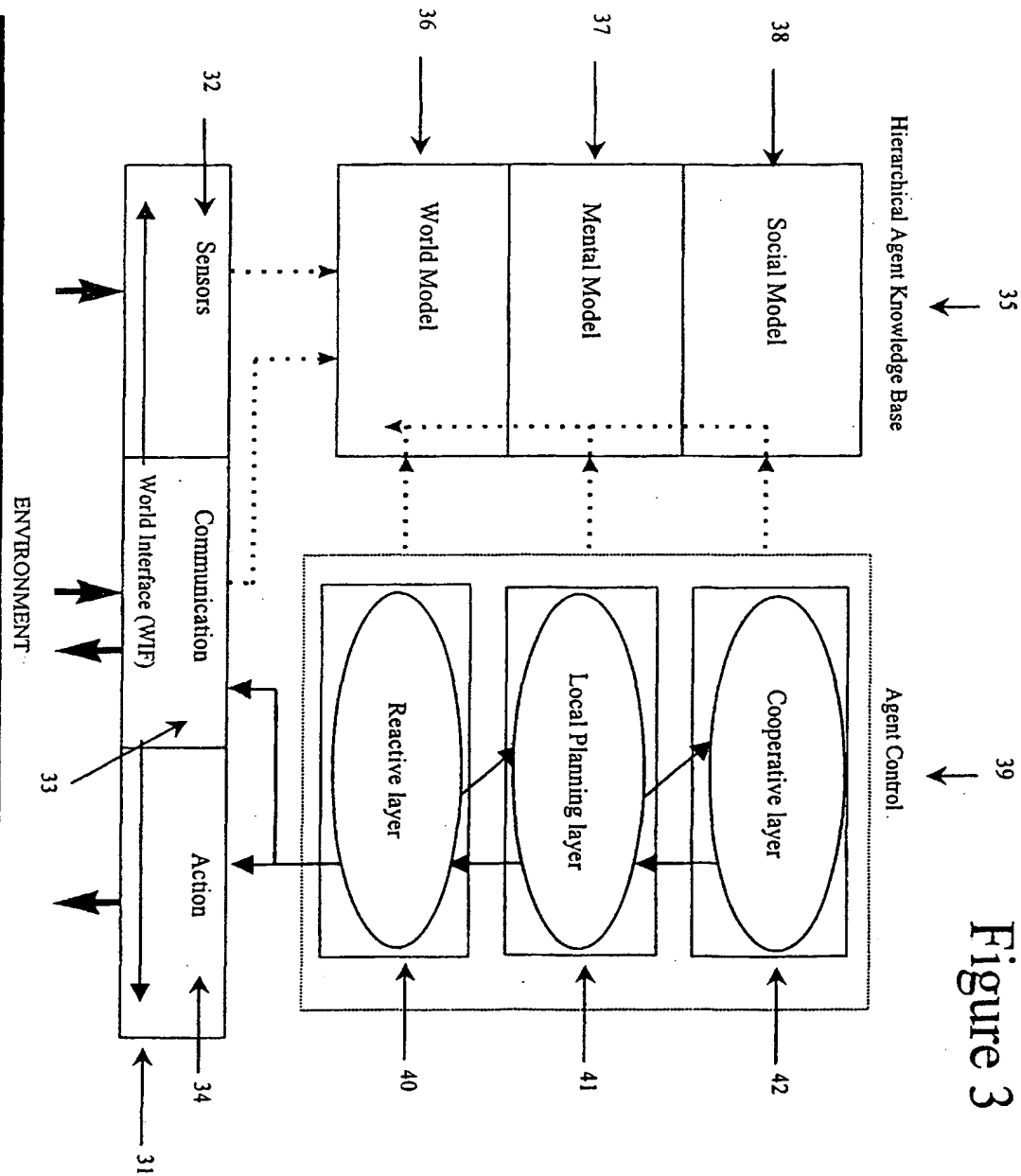
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Figure 1

3/4

Figure 3

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7   H04Q7/36

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7   H04Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 615 395 A (HITACHI,LTD.) 14 September 1994 (1994-09-14) claim 1; figures 5-8 ---	1,14,16
X	WO 99 60659 A (RAYTHEON COMPANY) 25 November 1999 (1999-11-25) abstract; claim 1 ---	1,14,16
X	GB 2 299 916 A (HITACHI LTD.) 16 October 1996 (1996-10-16) abstract; figures 1-6,14 ---	1
A	WO 97 08909 A (NOKIA TELECOMMUNICATIONS OY) 6 March 1997 (1997-03-06) abstract; claims 1,4 page 8, line 12 - line 19 ---	1,12-16
	-/--	

X	Further documents are listed in the continuation of box C.	X	Patent family members are listed in annex.

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Name and mailing address of the ISA	Authorized officer
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Patent document cited in search report		Publication date	Patent family member(s)		Publication date
EP 615395	A	14-09-1994	JP	6268574 A	22-09-1994
			CA	2118615 A	12-09-1994
			DE	69401672 D	20-03-1997
			DE	69401672 T	04-09-1997
WO 9960659	A	25-11-1999	AU	4308899 A	06-12-1999
			US	6236866 B	22-05-2001
GB 2299916	A	16-10-1996	JP	8289366 A	01-11-1996
			CN	1147189 A	09-04-1997
			HK	121097 A	12-09-1997
			KR	221416 B	15-09-1999
			SG	54296 A	16-11-1998
			US	6112081 A	29-08-2000
WO 9708909	A	06-03-1997	AU	3260495 A	19-03-1997
GB 2311191	A	17-09-1997	JP	2803716 B	24-09-1998
			JP	9247085 A	19-09-1997
			AU	721201 B	29-06-2000
			AU	1518997 A	18-09-1997
			GB	2350024 A,B	15-11-2000
			GB	2350026 A,B	15-11-2000
			US	5898682 A	27-04-1999
GB 2318483	A	22-04-1998	AU	4299097 A	15-05-1998
			WO	9818278 A	30-04-1998
			EP	0932994 A	04-08-1999
			JP	2001502862 T	27-02-2001
US 5638494	A	10-06-1997	CA	2119085 A	16-09-1995
			US	5802396 A	01-09-1998
			DE	19508940 A	26-10-1995
			GB	2289598 A,B	22-11-1995